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Atmospheric Cold Plasma via Fringe Field Enhanced Corona Discharge on Single Dielectric Barrier for Large-Volume Applications

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Abstract

This paper is to design and discuss on homogenous atmospheric cold plasma technique. Instead of using the needle tip with a small radius of curvature, this work utilized the twin tips with the sharp edge that can concentrate electric field around the edge of tips, allowing micro-discharge plasma at low power consumption. Our design structure shows a uniform atmospheric-air cold plasma for large-scale surface treatment applications. Furthermore, the designed large-scale atmospheric cold plasmas also provide a great benefit to environmental utilization.

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Here Plasma as a fourth state of matters which naturally occurs in suitable pressure condition at very high temperature [1]. There are many reports, demonstrating that plasma can be generated under the atmospheric conditions at room temperature [1-2]. Therefore, non-thermal plasma brings extremely beneficial to the broad area of applications [3]. With relatively low-power and atmospheric pressure generation, corona discharge has been extensively utilized in several applications, such as electrostatic precipitation, ozone production, and electrophotography [4]. Plasma is usually classified according to its gas temperature: non-thermal (cold) plasma and thermal plasma. Cold plasmas is suitable for biological-medical applications, food sterilization, and surface modification [3-4]. This paper herein proposes the design of cold plasma generation technologies for economically large-scale industrial applications. The key configuration of our gas discharge plasmas is to use corona discharge plasma in conjunction with single dielectric barrier discharge (SDBD). However, corona discharge is difficult to control and quickly proceeding to arc-flash with extremely high temperature up to some thousand kelvins [5-7].

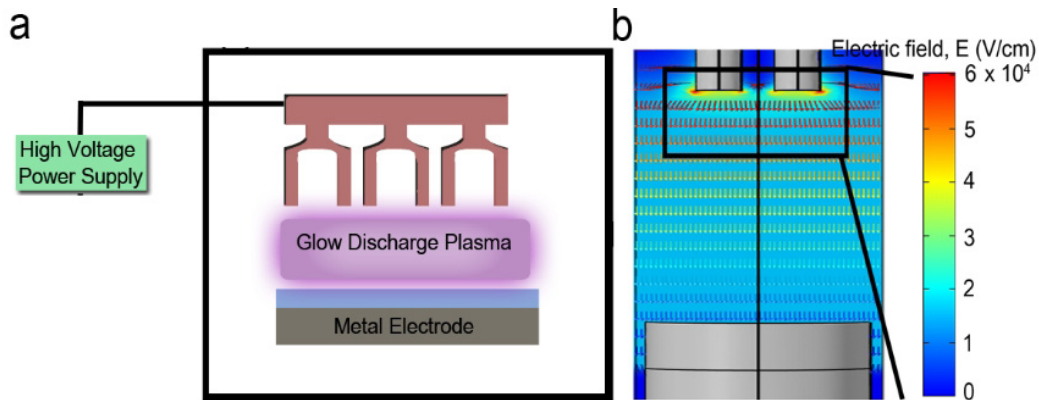


Fig. 1. (a) Schematic diagram of corona discharge plasma in conjunction with single dielectric barrier discharge (SDBD), (b) Electric field distribution

Fig. 1a shows a schematic of the overall experimental configurations used to generate the atmospheric-cold plasma. Metal tips served as top electrodes and connected to a low-frequency high voltage sinusoidal source. The metal counter electrode covered by a dielectric layer was directly grounded. Each top electrode comprises of two stainless steel tips. In this work, the atmospheric cold plasma under air ambient was accomplished by using a combination of single dielectric barrier discharge and corona gas discharge on the edge of stainless steel tips. Tips are wired together by epoxy holders. The gap distance between the top electrode and dielectric layer is designed to be adjustable for proper applications, typically in the range of ~ 5 mm to ~ 1 cm. The main gas utilized in this work is air. All the photos are taken by using a digital optical microscope. The commercial software COMSOL Multiphysics, Finite Element Method was employed to illustrate the electric field distribution between the two electrodes under plasma operation (Fig. 1b). The main electrodes were simulated with the similar dimension as in experimental design (Fig. 1). It is obvious that, under air ambient, there was no electrical breakdown or spark occurred because the 7 kV peak voltage with ~ 5 mm gap spacing yields the average electric field only $\sim 1.4 \times 10^4$ V/cm whereas the typical air breakdown voltage is $\sim 3 \times 10^4$ V/cm. However, by using the advantage of the localized fringe field at the edge of the tips, the localized electric field can be built up to $\sim 5 \times 10^4$ V/cm. The average field is relatively low and not damaging the organic materials.

Fig. 2a-d (left) illustrate the air diffuse plasma treated on objects with the gap spacing ~ 5 mm: Atmospheric-air cold plasma treated on (a) without sample, (b) rice grains, (c) Mung Bean and (d) flour wafer under the mixture of Ar/air. The corona streamer appears as a faint filamentary with UV radiating outward from electrodes, proving the

availability of designed configuration for generating large scale atmospheric cold plasma. Moreover, corona discharge can give rise to ozone (O₃) generation as a by-product of this system. Ozone in non-equilibrium air plasmas at atmospheric pressure is generated by a two-step process as follows: (i) Generation of oxygen free radicals by ionic processes, (ii) Generation of ozone by free radical reactions. However, details of reaction and ozone generation efficiency are beyond the scope of this paper and subjected to be future researches. It is important to note that there are two types of corona discharges: positive and negative, depending upon the polarity of electric field and the electrode geometrical configurations [6]. The positive corona discharge plasma is unsteady and noisy, and can subsequently reach the sparking limit. Therefore, in this designed configuration, the dielectric covering plane electrode is needed to prevent the arc and to stabilize the plasma process.

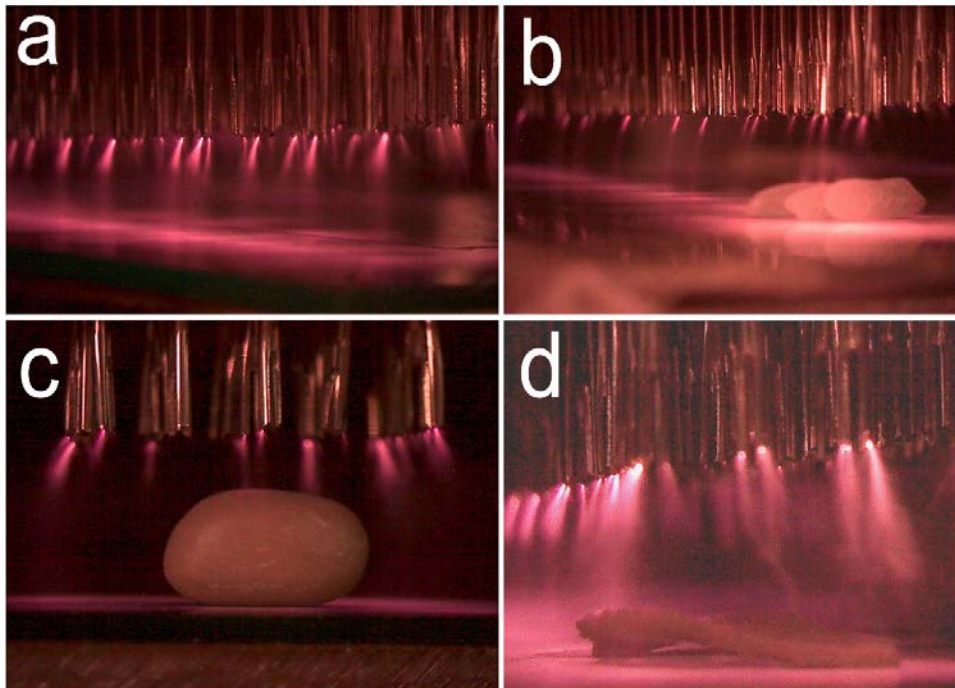


Fig. 2. Optical micrograph of atmospheric cold plasma treated on various samples.

In order to prove that the cold plasma is generated in an atmospheric air pressure, a white paper was placed on glass exposed to glow discharge (Fig. 3e). After remaining in contact with plasma for 5 minutes, there is no thermal damage, burning and dark spot in the paper surface. Also, the Thermal Imager and Thermopoint (AGEMA Infrared Systems) were utilized to measure the real time temperature of operated sample including before and after plasma operation. The result of Thermal Imager and Thermopoint shows well agreement with the average temperature of sample $\sim 25.5^{\circ}\text{C}$, which is closing to back ground temperature ($\sim 25^{\circ}\text{C}$) even under operation. Overall result suggests that the appeared plasma streamer, filling most of the volume, is mainly governed by positive corona discharge. The active species (charged particles, excited particles, radicals, UV photons, etc.) are strongly dependent on the electrode distance and gas ambient. In addition, the mixture of Ar/air allows more homogenous plasma emission than pure surrounding air.

The proposed method provides the cold plasma via fringe field enhanced corona discharge under atmospheric pressure and air ambient without the requirement of vacuum apparatus, making it low cost and high potential to be

widely used in industries. The key mechanism is to maximize the field strength near electrodes by using sharp edge tips, allowing large volume plasma generation. The power consumption of this method is relatively low compared to other methods [5-7]. Therefore, it is feasible to implement the large-scale atmospheric cold plasma in an efficient and effective way for plasma surface treatment applications.

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